

RHEOLOGY OF SOY PROTEIN DISPERSIONS. EFFECT OF HEAT AND OTHER FACTORS ON GELATION¹

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ABSTRACT

The rheological properties of relatively concentrated aqueous dispersions of a commercial edible isolated soy protein preparation were studied. In the absence of heat, the viscosity rises exponentially with increased concentration. In concentrations above 7% by weight, heat causes thickening and then gelation, the temperature threshold being 65°C. Rate of gelling and gel firmness are dependent primarily on temperature, time of heating, and protein concentration. In concentrations 8–14%, gels are formed within 10 to 30 min. at 70°–100°C., but are disrupted if overheated at 125°C. Above 16 to 17% the gels are firm, resilient, and self-supporting, and less susceptible to disruption by overheating. The addition of salts to 10% dispersions generally lowers the viscosity of the unheated dispersions, but raises that of the heated dispersions. The viscosities of both unheated and heated 10% dispersions are raised by added soy oil, soy lecithin, wheat starch, carboxymethylcellulose or carrageenan. The specific disulfide-reducing agents, sodium sulfite and cysteine, profoundly lower the viscosity of both unheated and heated 10% dispersions, and prevent gelation.

With the recent increase of interest in the food uses of edible isolated soy protein (1–7), the desirability of quantitative information on its functional properties has become more apparent. Soy protein in aqueous dispersion, when appropriately manipulated, displays such properties as moisture-absorbing, emulsifying, whipping, thickening, and the capabilities of forming films, fibers, doughs, and gels (8–10). These attributes, and especially the ability of the gel structure to act as a matrix in holding moisture, lipids, polysaccharides, and other

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ingredients, are of significance in many food applications. Of special interest as to cereals, meat, and dairy products is information on the rheological behavior of soy protein dispersions in the viscous and gelled states.

Earlier interest in soy protein centered mainly on adhesive applications of its aqueous alkaline dispersions, and their rheology, primarily for paper coatings, in which large amounts are used (11-15). In this and other industrial applications of present and past interest, such as in "spinning dopes" for AZLON-type textile fibers, studies on the rheology of the alkaline dispersions have been concerned mainly with their fluidity and conditions for avoiding gelling, which may occur on exposure of unhydrolyzed soy protein at concentrations higher than 12% to high alkalinity (12,13). However, a study of the viscosity and gelling of alkaline soy protein dispersions is not a part of the present study.

For food applications the emphasis has been on conditions favoring gel formation; here neutral dispersions are employed and are gelled by heat (16-19).

One patent (16) has enumerated the following preferred conditions to transform a "gel-precursor" into a chewy gel (defined as having resilience, elasticity, and resistance to shear): concentration in the range 20-30%, pH in the range 6.5-7.5, and temperature of heat gelation 105°-120°C.; heating beyond that necessary for gel formation was not "observed to influence the character of the gel to any appreciable extent, although some deleterious effect may be obtainable by unreasonably prolonged heating."

Another patent (17) reports gelling temperatures in the range 65°-100°C., pH 5-9, and concentrations 10-50% (but refers to the spray-dried aqueous extract of alcohol-treated flakes, containing about 54% protein, not to an isolate).

A third patent (18) refers to a thermally irreversible gel obtainable from a protein isolate (derived from alcohol-contacted soybean material) at concentrations above 5-8% at neutral pH, and at temperatures 65°-92°C. Dispersions of curd made up at pH values as low as 4.9 could be gelled at 92°C., even if the curd had been precipitated with sulfur dioxide.

According to another patent (19), shredlike masses are produced under violent agitation by heating a 32% aqueous isoelectric soy protein isolate to a preferred temperature of 182°C.

The gelling conditions outlined in the above-described patents for the most part specify protein concentrations of 18% or higher, at which firm gels may be expected to form. No attempt was made by

the inventors to determine in a quantitative manner the various factors involved in the thermal sol-gel transition relationship in the definitive lower range of soy protein concentrations. It is with this subject that this study is concerned.

For practical reasons a particular commercially available, unhydrolyzed, neutral, water-dispersible sodium soy proteinate was chosen for detailed study. It is recognized that the properties of such a preparation may vary, depending on the method and control of manufacture. Preliminary comparison showed minor differences in rheological behavior among proteinates of different manufacture, but further investigation is needed to assess the influence of processing variables. The techniques described are considered applicable to the characterization of edible soy protein isolates of other origin, and the data derived should have value in application to various types of foodstuffs.

Materials and Methods

Materials. The sodium soy proteinate under investigation in this report is a commercially available product² having the following proximate analysis: moisture, 5.3%; protein (N \times 6.25), 92.5%; ash, 4.1%; crude fiber, 0.13%; pH in 10% aqueous dispersion, 6.9–7.0. One specific lot was used in all experiments for the sake of uniformity, with one exception (the data in Fig. 2 were obtained with a different lot). However, viscosity and gelation tests on six different lots of the material showed only minor variations. This proteinate is manufactured from dehulled, hexane-defatted soy meal by warm aqueous, mildly alkaline extraction, clarification of the extract by thorough separation of the insoluble matter, and acidification to form "curd," which is separated from the "whey," washed, neutralized with sodium hydroxide, and spray-dried (9–11,13,20,21).

Distilled water was used in making up all dispersions; chemicals were reagent grade except for sodium hexametaphosphate. The degummed soy oil, lecithin, wheat starch, carboxymethylcellulose, and carrageenan were of commercial origin.³

Dispersion. Dispersions of the proteinate as concentrated as 14% in water were made up on a weight percentage basis by adding the proteinate (as obtained) to the water with constant stirring, using a propeller-type agitator. All additives were mixed into the dispersions in the wet form after they were suspended in part of the water required for the weight basis. To ensure completeness of dispersion,

²PROMINE-D brand of sodium soy proteinate, manufactured by Central Soya Co., Chemurgy Division, 1825 N. Laramie Avenue, Chicago, Ill. 60639.

³Degummed soy oil and lecithin from Central Soya Co.; starch (STARBAKE 100) from Hercules Powder Co., Wilmington, Delaware; carboxymethylcellulose (CMC-70SH) from Hercules Powder Co.; carrageenan (Type 2) from Marine Colloids, New York, N.Y.

additional stirring was given by a high-speed blender, after which air was removed by centrifugation for 1 min. at an r.c.f. of 250. Under these conditions there was no perceptible sedimentation, and the proteinate, on an empirical basis and for the practical purposes of this study, is considered to be completely water-dispersible (22). Dispersions in the higher concentrations of 16–20% were more readily manipulated in a silent-cutter type of machine, and the air was removed under vacuum.

Gelation. All heating experiments were carried out at the specified temperatures (water bath or steam cooker-canner) after each sample of 320 g. of air-free dispersion was sealed in a No. 1, C-lined, commercial tinned can, with the cans initially at room temperature. After the specified time interval of heating, the cans were immediately plunged into an ice bath so as to cool quickly to room temperature. Unless otherwise specified, the heating temperature was 100°C. for a duration of 30 min.

Viscosity Measurements. Viscosities of fluid and gelled dispersions were determined at 25°C. on a Brookfield LVT model viscometer, using the Brookfield Helipath stand with the series of T spindles furnished, and other spindles as necessary. The calibration of this instrument was checked with two different viscosity standards. Most of the Brookfield data were measured at several speeds of rotation, but those recorded are given mainly at 1.5 r.p.m. Owing to the thixotropic properties of both the fluid dispersions and the gels, the viscosity data are reported as "apparent viscosity" for the spindle and speed designation. The Helipath permits relative measurements of paste and gel viscosities by slowly lowering the spindle at low rotational speeds through the matrix, thus measuring undisturbed structure at all times.

The Brookfield instrument was used to obtain all the viscosity data except in the study of the temperature threshold of thickening, for which viscosity measurements were made on a Brabender VISCO/amylo/GRAPH, model AV1.

Results and Discussion

Temperature Threshold of Thickening. Aqueous dispersions of sodium soy proteinate were made up in concentrations of 8, 10, and 12% by weight. These limits of concentration were dictated by previous findings that at concentrations above 12%, the heat-produced gels had rigidity beyond the capacities of the viscometers employed; on the other hand, at concentrations below 8%, the gel structure formed was considered too thin in consistency to be of interest in food applications where structure is desired.

These dispersions were subjected to controlled heating with rotation in the VISCO/amylo/GRAPH at the programmed rate of 1.5°C. rise per min., starting at room temperature, and rising to 90°C. The results, as shown in Fig. 1, indicate that in this apparatus thickening

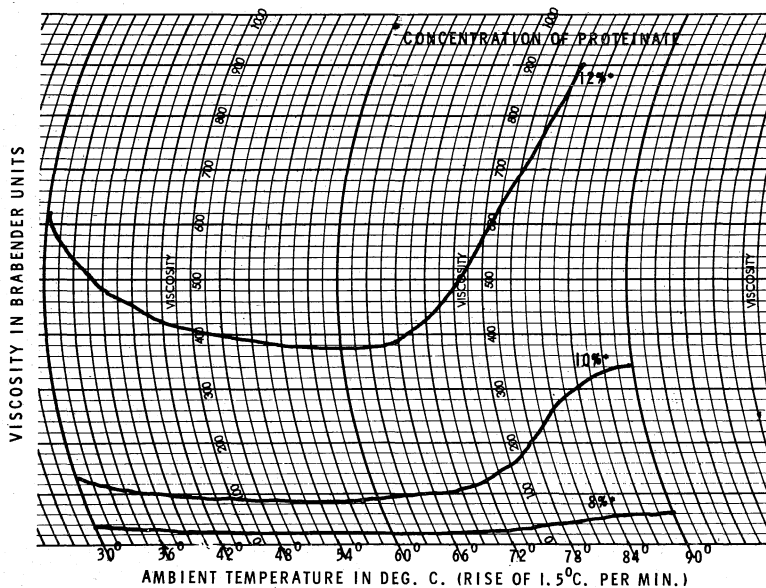


Fig. 1. Temperature-viscosity curves showing sol-gel transition ranges for 8, 10, and 12% aqueous dispersions of sodium soy proteinate (concentration in terms of percent by weight), using VISCO/amylo/GRAPH.

first becomes apparent in the range 60°–70°C., being quite marked at 65°C. for the 12% concentration, and barely perceptible for the 8% concentration. Below this temperature range, thinning occurs as the dispersion warms up from room temperature. However, this instrument, because of the continuous fast rotation feature during its operation, inherently causes disturbance of the gel structure during the gel formation, and the open cup permits evaporation of the dispersion. For these reasons all other tests were carried out in sealed tinned cans heated with minimum disturbance of the contents during the gelling stage, and viscosity measurements were made on the Brookfield viscometer after the gels had cooled to 25°C.

Effect of Concentration on Viscosity. Figures 2 and 3 show that in the unheated dispersions the viscosity rises exponentially with increase in concentration, a behavior typical of macromolecular dispersions. This conclusion also holds for the heated gels.

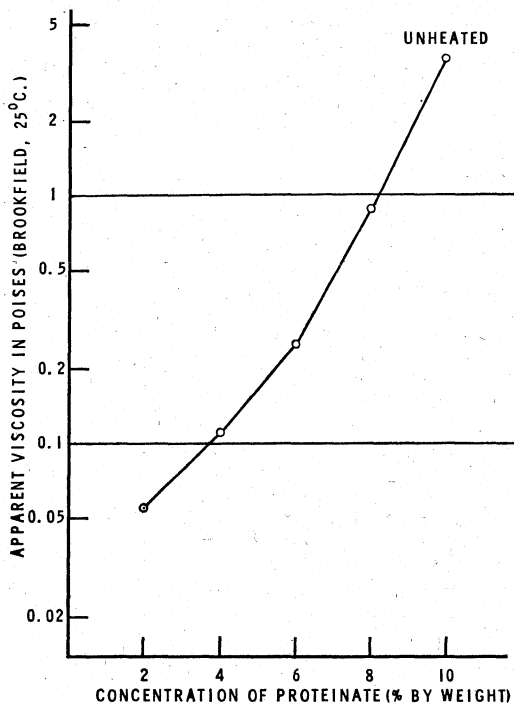


Fig. 2. Effect of concentration on apparent viscosity of unheated sodium soy proteinate dispersions (using spindle No. 2 at 60 r.p.m.).

Effect of Spindle Speed on Viscosity Measurements. According to Fig. 4, dispersions of sodium soy proteinate at 8 and 10% concentrations are non-Newtonian both in the unheated and heated states. This is true also for the lower concentration of 6%, unheated. In all cases the viscosity is dependent on the rate of shear applied.

Effect of pH. At pH 6 the viscosity of 10% unheated sodium soy proteinate drops considerably below that at pH 7 or above, as shown in Fig. 5. This is probably due to lower solubility or aggregation of the proteinate at pH 6, which is overcome by heating, the viscosity of the heated 10% dispersion at pH 6 being equal to that at pH 7 and 8. The slight increase in viscosity of the unheated 10% dispersion at pH 8 and 9 as compared with that at pH 7 is probably due to enhanced solubility at the higher pH values. The drop in viscosity in the heated dispersion at pH 9 may be indicative of some hydrolytic action.

Gelation Temperature-Time Relationship. In Fig. 6, the viscosity of an 8% dispersion is shown to rise to a maximum upon 30 min. of heating at 100°C., followed by a sharp drop in the next 30 min. This

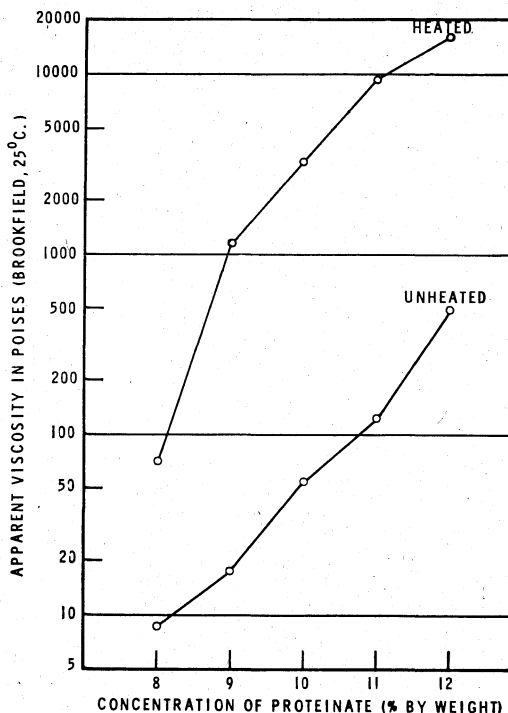


Fig. 3. Effect of concentration on apparent viscosity of unheated and heated sodium soy proteinate dispersions (using following spindles at 1.5 r.p.m.: No. 1 for unheated 8 and 9%, No. 2 for unheated 10%, No. 3 for unheated 11 and 12%; TA for heated 8%, TF for heated 9, 10, 11, and 12%, but 0.3 r.p.m. for heated 12% instead of 1.5 r.p.m.). Heating: 100°C. for 30 min.

drop is much less precipitous when the heating is carried out at 90°C., and is practically absent at 80°C. In the case of a 10% dispersion, the maximum viscosity occurs at 45 min. of heating at 100°C., and with a 12% dispersion, at 60 min. Neither the 12 nor the 10% dispersion shows the marked drop in viscosity displayed by the 8% at 100°C., even when heating is prolonged for 2 hr. more.

An even more interesting set of curves is presented in Fig. 7. In this series, the time of heating at various temperatures was kept constant at 30 min. The 8% dispersion displays maximum viscosity at about 80°C., the 10% at 100°C., and the 12% at 110°C. At all three of these concentrations, viscosity drops tremendously with heating at 125°C., the decrease for the 12% being from 20,000 poises to the vicinity of 1 poise, and down to 0.1 poise for the 10%. Solubility of the protein was apparently unaffected by this relatively high temperature, as shown

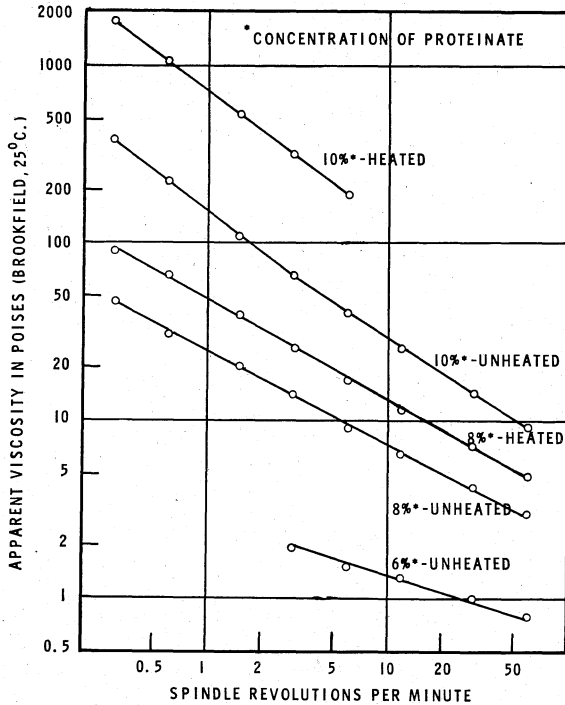


Fig. 4. Effect of spindle speed on apparent viscosity of 6, 8, and 10% unheated and heated sodium soy proteinate dispersions (using following spindles: No. 1 for unheated 6%; No. 3 for unheated 8%; No. 2 for heated 8%; No. 3 for unheated and heated 10%). Heating: 100°C. for 30 min.

by no sedimentation after centrifuging. Also, the heat-disrupted gel lost the capability to gel when heated.

However, at 14% concentration, the viscosity of the gel obtained by heating (125°C.) for 30 min. is 5,130 poises, and the gels at 16, 18, and 20% concentrations heated under the same conditions are rigid, with apparent viscosity beyond the range of the viscometer, that is, greater than 33,300 poises (not in the range of Fig. 7). Thus the gel breakdown experienced by the dispersions of 14% or lower concentration when heated for 30 min. at 125°C. is not exhibited by dispersions of 16% or higher concentration (see caption of Fig. 7).

It may be concluded from Figs. 6 and 7 that the gel stability under stress conditions of heating is dependent primarily on the concentration of the soy proteinate for any given temperature and time; the higher the concentration, the firmer the gel, and the more heat-stable. On the other hand, with the higher concentrations, such as the range 16–20% or higher, rigid gels can be derived readily without resort to

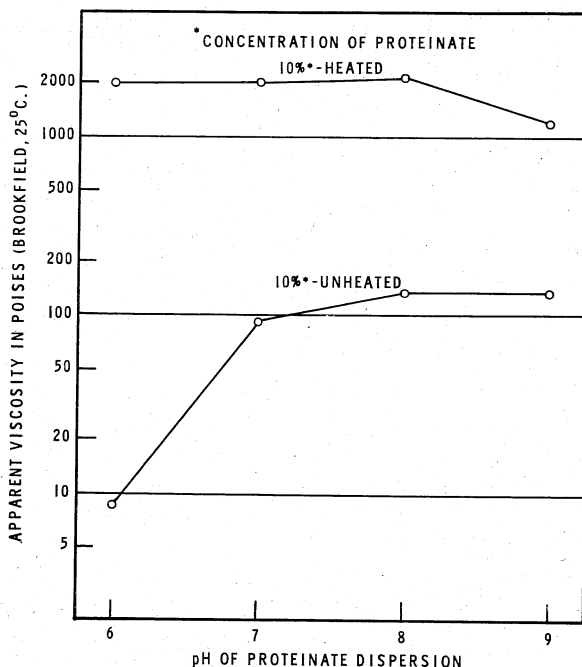


Fig. 5. Effect of pH on apparent viscosity of 10% unheated and heated sodium soy proteinate dispersions (using following spindles at 1.5 r.p.m.: No. 1 for unheated pH 6; No. 3 for unheated pH 7, 8, and 9; TF for heated pH 6, 7, 8, and 9). Heating: 100°C. for 30 min.

drastically high temperatures or prolonged heating periods, 10 min. at 70°C. being sufficient for heat-gelation, as shown by independent experiments.

Gelation Firmness-Concentration Dependency. Four dispersions were made up at 12, 13, 14, and 15% concentrations by weight. The air-free samples were steam-cooked for 30 min. at 100°C. in No. 1, C-lined cans; to release the gels, the can ends were removed and the can bodies were slitted. Figure 8 illustrates the rigidity and sliceability of the cylindrical gel structures. The limpness of the slice is least for the highest concentration, and so is the sag of the cylindrical cross-section resting horizontally on the supporting surface.

As a "Sag Index," a plot is given in Fig. 9 of the ratio of the difference of diameters of maximum width and height (of cross-section of gels of Fig. 8) to their sum, $D_w - D_h / D_w + D_h$, vs. the concentration. Extrapolation indicates that sag is zero at approximately 16.5% concentration. This criterion is corroborated by the 16, 18, and 20% gels described in the previous section, which demonstrated no-sag, and which were rigid and elastic.

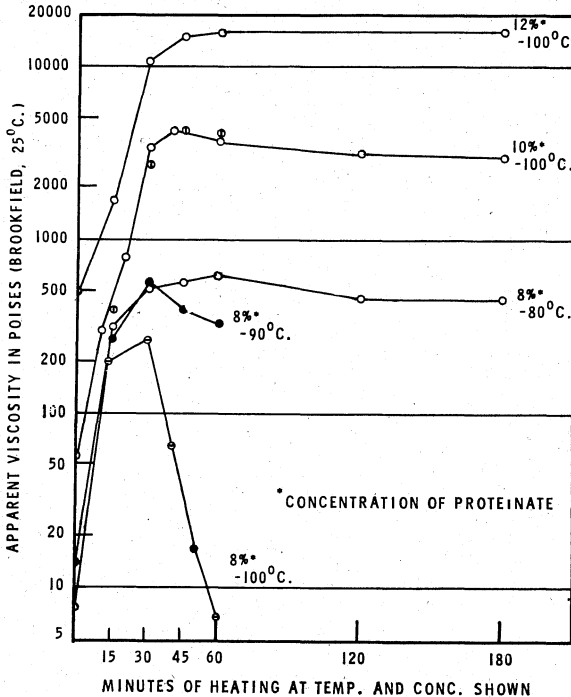


Fig. 6. Effect of time interval of heating on apparent viscosity of 8, 10, and 12% sodium soy proteinate dispersions (using following spindle-speed combinations: TF spindle at 1.5 r.p.m. for 8 and 10%; TF spindle at 0.3 r.p.m. for 12%; except for 0 min. at which TA-1.5 r.p.m. was used for 8, 10, and 12%).

Influence of Additives on Heat-Gelation. In almost all food applications it is to be expected that soy protein isolate will be used in admixture with other ingredients; this poses a possibility that some of these may affect the heat-gelation of the proteinate. A cursory survey of several materials encountered in the food field shows that very few are likely to be troublesome in this regard. This conclusion is supported by viscosity data given in Tables I and II. Table I lists several sodium salt additives (chloride, nitrate, dihydrogen phosphate, and hexametaphosphate), and Table II lists several lipid and polysaccharide additives (all additives are given in weight percent of a 10% sodium soy proteinate dispersion). At low concentrations (0.05 and 0.1%) the salts of Table I have relatively minor effect on the viscosity of the unheated and heated dispersions; at higher concentrations (0.5 and 1%) the effect of the salts is to lower the viscosity of the unheated dispersion, and to raise that of the heated. This is so for all of the salt additives with the exception of the hexametaphosphate. The lipids (degummed

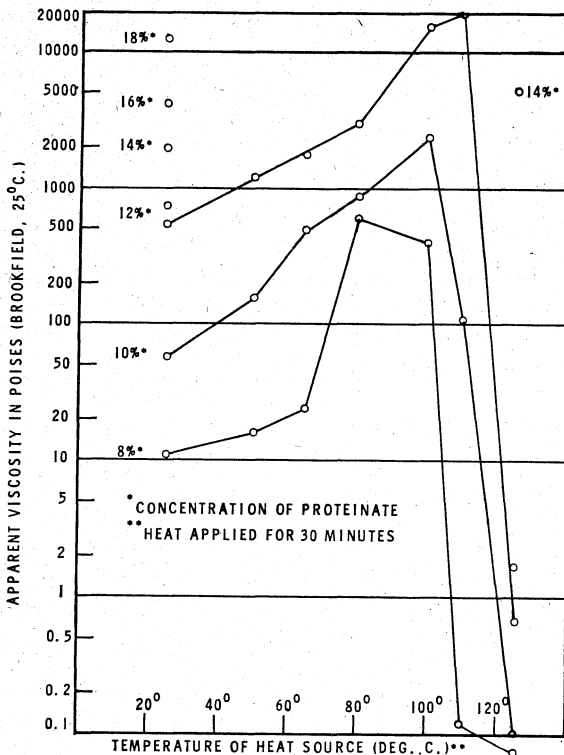


Fig. 7. Effect of temperature on apparent viscosity of 8, 10, 12, 14, 16, and 18% sodium soy proteinate dispersions held for 30 min. at ambient temperature shown (using following spindle-speed combinations: TF spindle at 1.5 r.p.m. for all, with exceptions as follows, TA-1.5 r.p.m. for 8%-25°, 8%-50°, 8%-65°, 10%-25°, 10%-110°, 12%-125°; TF-0.6 r.p.m. for 18%-25°; TF-0.3 r.p.m. for 12%-100°, 12%-110°; No. 1-60 r.p.m. for 8%-110°, 8%-125°, 10%-125°C.).

At the higher concentrations of 16, 18, and 20%, heating the dispersions at 125°C. for 30 min. formed rigid gels, all with apparent viscosities higher than 33,300 poises (the upper limit of measurement of the instrument using TF spindle of the Helipath at 0.3 r.p.m.). The viscosities of the unheated 14, 16, and 18% dispersions are in the figure, but only that of the heated 14% dispersion was low enough to permit locating it on the graph.

soy oil and lecithin) and the polysaccharides (wheat starch, carboxymethylcellulose and carrageenan) increase the viscosities of the unheated dispersions and of most of the heated gels.

The situation is different for the two reducing agents sodium sulfite and cysteine, which markedly reduce the apparent viscosities of both the unheated dispersions and the heated gels, as shown in Table III. In the case of the other reducing agents, sodium nitrite lowered the viscosity of the unheated dispersion, but had relatively less effect on the gel, slightly lowering the viscosity of the latter at 0.01 and 0.1%, and

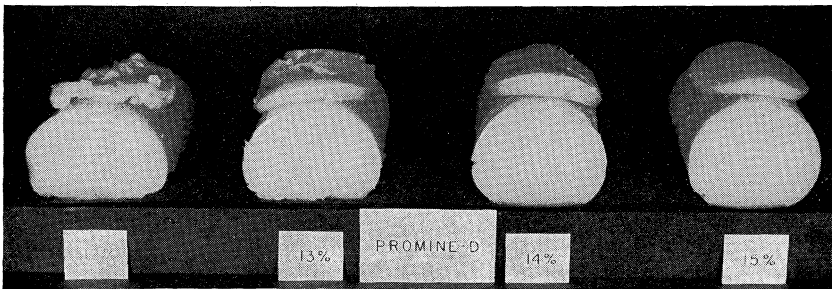


Fig. 8. Photograph illustrating appearance of gels from 12, 13, 14, and 15% sodium soy proteinate dispersions heated at 100°C. for 30 min. in No. 1 C-lined tinned cans.

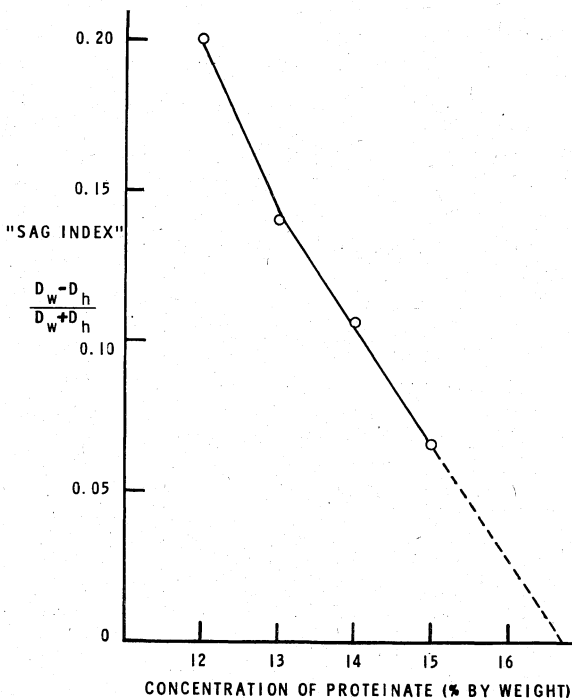


Fig. 9. "Sag Index"—concentration relationship for gels illustrated in Fig. 8. "Sag Index" calculated as ratio of difference of major width and major height diameters of cross-section of gels to their sum: $D_w - D_h / D_w + D_h$.

raising it at 0.5%. Sodium hypophosphite at 0.05% raised the viscosity of both the unheated and heated dispersions, and at 0.5%, that of the heated. The behavior of the nitrite and hypophosphite is not dissimilar from that of the salts of Table I. Ascorbic acid at 0.5% raised

TABLE I
EFFECT OF VARIOUS SALINE ADDITIVES ON THE APPARENT VISCOSITY OF A 10% SODIUM SOY PROTEINATE DISPERSION,^a UNHEATED AND HEATED

Type	ADDITIVE		APPARENT VISCOSITY ^b	
	Conc. in Dispersion	%	Unheated	Heated
			<i>poises</i>	<i>poises</i>
Control			43	3,470
NaCl	0.1		32	3,400
NaCl	1		18	6,000
NaNO ₃	0.05		53	3,930
NaNO ₃	0.5		37	4,470
NaH ₂ PO ₄ ·H ₂ O	0.05		45	3,530
NaH ₂ PO ₄ ·H ₂ O	0.5		28	3,600
(NaPO ₃) _n	0.05		47	2,670
(NaPO ₃) _n	0.5		25	3,200

^a pH at or adjusted to 6.9-7; heating done at 100°C. for 30 min.

^b Viscosities of unheated dispersions measured by TA spindle at 1.5 r.p.m.; of heated dispersions by TF spindle at 1.5 r.p.m.

TABLE II
EFFECT OF VARIOUS LIPID AND POLYSACCHARIDE ADDITIVES ON THE APPARENT VISCOSITY OF A 10% SODIUM SOY PROTEINATE DISPERSION,^a UNHEATED AND HEATED

Type	ADDITIVE		APPARENT VISCOSITY	
	Conc. in Dispersion	%	Unheated	Heated
			<i>poises</i>	<i>poises</i>
Control			27 ^b	2,330
Degummed soy oil	5		800	2,730
Degummed soy oil	20		3,270	5,330
Soy lecithin	5		1,330	2,400
Soy lecithin	10		3,130	4,600
Wheat starch ^c	5		48 ^b	2,870
Wheat starch ^c	10		117 ^b	>6,660
Carboxymethylcellulose ^d	0.1		300	1,670
Carboxymethylcellulose ^d	1		2,600	3,930
Carrageenan ^e	0.1		467	2,270
Carrageenan ^e	1		2,130	4,400

^a pH at 6.9-7; heating done at 100°C. for 30 min.

^b These viscosities measured by TA spindle at 1.5 r.p.m.; all others by TF spindle at 1.5 r.p.m.

^c Starbake 100, Hercules Powder Co., Wilmington, Del.

^d CMC-70SH, Hercules Powder Co., Harbor Beach, Mich.

^e SeaKem Type 2, Marine Colloids, New York 4, N.Y.

the viscosity of the unheated, and lowered that of the heated dispersions; at 0.05% there was less effect. This behavior of ascorbic acid is somewhat anomalous, and should be studied further.

Sodium sulfite and free cysteine are known to be specific and effective reducing agents for the disulfide bonds of proteins (23), and their thinning action on both sol and gel forms of the 10% sodium soy proteinate dispersions is probably exerted through cleavage of these bonds. This conclusion is supported by the ineffectiveness of two other reducing agents, sodium hypophosphite and sodium nitrite, which

TABLE III
EFFECT OF VARIOUS REDUCING AGENTS ON THE APPARENT VISCOSITY OF A 10% SODIUM SOY PROTEINATE DISPERSION,^a UNHEATED AND HEATED

Type	ADDITIVE		APPARENT VISCOSITY	
	Conc. in Dispersion		Unheated	Heated
	%		poises	poises
Control			37 ^b	3,400
Na ₂ SO ₃	0.01		14.7 ^b	2,200
Na ₂ SO ₃	0.1		0.4 ^c	6.7 ^c
Na ₂ SO ₃	0.5		0.2 ^c	1.3 ^c
NaNO ₂	0.01		18.8 ^b	2,870
NaNO ₂	0.1		28.7 ^b	2,530
NaNO ₂	0.5		20 ^b	4,600
NaH ₂ PO ₄ ·H ₂ O	0.05		52	3,870
NaH ₂ PO ₄ ·H ₂ O	0.5		33	5,470
Cysteine·HCl	0.05		0.4 ^c	600
Cysteine·HCl	0.5		27 ^b	2,400
Ascorbic acid	0.05		49 ^b	3,800
Ascorbic acid	0.5		467	2,800

^a pH at or adjusted to 6.9-7; heating done at 100°C. for 30 min.

^b Measured by TA spindle at 1.5 r.p.m.; other viscosities measured by TF spindle at 1.5 r.p.m.

^c These viscosities measured by No. 1 spindle at 60 r.p.m.

presumably have no action on the disulfide linkage. It has been postulated that ascorbic acid can reduce the disulfide bond (24), but this is not as well documented as in the case of sodium sulfite and the thiols (23).

However, even sodium sulfite becomes ineffectual in preventing gelation when the concentration of the proteinate is made high enough. In one study an unheated 20% dispersion of the commercial sodium soy proteinate had an apparent viscosity of 9,500 poises in the presence of 0.5% sodium sulfite, compared to 32,000 poises for the dispersion without sulfite (measured on Helipath with TF spindle at 0.3 r.p.m.). The gels formed from these dispersions, when heated at 100°C. for 30 min., were too rigid in both cases for their viscosities to be measured, but the gel containing sodium sulfite was somewhat less firm than the other, and was friable rather than resilient. In another study a laboratory-prepared sodium soy proteinate made from curd precipitated with sulfur dioxide formed a rigid gel when heated at 125°C. for 30 min. at 20% concentration, but failed to gel when heated at 100°C. for 30 min. at 10%; the commercial sodium soy proteinate gelled under both sets of conditions.

Mechanism of Heat-Gelation. The irreversible heat-setting of sodium soy proteinate dispersions to a gel state is a heat-denaturation phenomenon practically by definition. At concentrations of 6% and lower, gelation does not occur, although there is a small increase in viscosity. The gel rigidity on heating is primarily dependent on concentration,

complete self-support becoming evident in the concentration range 16–17% by weight in aqueous dispersion.

According to Ferry (25), gels of denatured proteins involve first an unfolding or extension of the corpuscular or globular protein into a more asymmetric shape, the protein backbone chain assuming a more or less extended and irregular form, and exposing reactive groups and also nonpolar groups during the unfolding, making them less hydrophilic. Association of the chains by cross-links spaced some distance apart, and also by localized and nonlocalized attractive forces (including hydrogen bonding), lead to the formation of a three-dimensional network throughout the sample, in which the "gel fraction" approaches unity, and in which rigidity is enhanced by further cross-linking taking place during the heating.

The irreversibility of the soy proteinate heated gels indicates that primary covalent bonds are involved in the cross-linking. The marked effect of sodium sulfite or cysteine in preventing gelation of a 10% dispersion points to the possibility of one type of cross-linking in their absence being promulgated by the sulfhydryl-disulfide chain reaction described by Jensen (26) for egg albumen and serum albumin. However, the ineffectiveness of sulfur dioxide treatment at 20% concentration leads to the conclusion that one or more other primary bonds may be involved in the cross-linking, such as formation of amides. Elucidation in more detail of the mechanism of gel formation and disruption in heated soy proteinate dispersions will have to await the results of further investigations.

Meanwhile, the sparseness of information on the precise mechanisms need in no way delay the continuing application of the gel phenomenon to the formulation of new and improved processed foods.

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